RADIOSITY MODELING FOR REMOTE SENSING APPLICATIONS

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We have found that the radiosity method has some unique applications in remote sensing that were not possible using conventional methods. We applied the radiosity method to model the transport of light inside of plant canopies, to simulate of atmospheric effects and to nonlinear spectral mixing. This work has been supported by the Remote Sensing Science Program (RSSP) and other grants from NASA.

Our work using the radiosity method started by investigating the multiple reflections between two rectangular surfaces which were subdivided into 16 by 16 patches. From this very simple model we started to investigate how we could apply the radiosity method to plant canopies. We developed a raytracing based view factor algorithm that generated fisheye views from randomly oriented disks into their surroundings. By changing the resolution of the fisheye image we could control the sparseness of the viewfactor matrix and use simple runlength encoding to store matrices of 20,000 by 20,000 and solve them iteratively using the Gauss-Seidel iteration scheme. At the same time we performed a statistical analysis of the viewfactors to layers of disks and found that we might be able to come up with viewfactors between layers of leaves rather than between individual leaves. This lead to a very simple radiosity model for horizontal leaves in discrete layers which could be solved very fast on an IBM PC. At that time we were not sure if our radiosity model was correct and we had to prove that the results were the same as for the radiative transfer methods. We found the equivalent problem solved in a book by Ross (1981). Bill Powers helped us to derive a finite difference equation for the up and down welling radiances in a layered canopy. The radiances are weighted sums of the radiosities. It turned out that by taking the limit on the leaf density, the difference equations turned into the differential equations of the radiative transfer method. Bill came up with an analytical solution for the radiosity equations and performed the limit on the resulting very complicated equations which again converged to the analytical solution of the radiative transfer differential equations. Using the raytracing approach we found some new ways to deal with partially illuminated disks. Rather than breaking them up into smaller patches we "smeared" the incident light from the sun over the whole disk and used that to perform the radiosity calculation. In the end we computed the amount of light in the shadow as just due to the reflected or transmitted radiosities from the surrounding disks. In the illuminated part we added the multiple scattered part to the solar light. A very curious effect was observed for disks with high reflectance. In lower layers the light increased! By that time we were building a large scale model of a canopy containing over 12,000 styrofoam disks mounted in 15 frames of 10 by 10 feet size. By taking images with a CCD camera we were able to measure the increase of light of up to 30 % for the third layer. The measured values from the undersides of the disks followed our model calculations very well. Measured intensities of illuminated disks in the upper layers showed considerable variations because of the non-Lambertian character of the disks and problems related to the CCD camera. We are still analyzing some of the data and are still making improvements on the canopy setup which is non-trivial considering the large size. We have painted a couple of layers with green Latex paint and performed spectral measurements. We believe that the radiosity method was well suited for this experiment. The results of a radiative transfer calculation are in terms of radiance which is basically the average intensity over the canopy. Using the radiosity method we get intensities for each point on a surface and a picture that we can compare with a CCD image. We think that the radiosity method is able to model realistic plant canopies that are usually discontinuous, have clumps of leaves and voids. In contrast to the radiosity method, the radiative transfer method is a volumetric balance equation and cannot deal explicitly with discrete surfaces.

During 1991-1992 we worked on the "volume radiosity" or as we called it the "extended radiosity". We wrote a paper concerned with modeling obscurants and implemented a rather simple but computationally complex algorithm to compute the volume radiosities in a participating medium above a flat surface with different reflectances. Using simple raytracing and interpolation routines we rendered the radiosity solutions. To our surprise we observed the adjacency effect, i.e. when two surfaces of different reflectance are observed through a scattering medium photons from the brighter surface will scatter into the volume above the darker surface and "blur" the discontinuity. This effect can be observed during rain and snow storms, i.e. outlines of trees and mountains in the distance become blurred. It is a small effect and remote sensing scientists have observed and modeled it only in the last 12 years using rather complex 3-d radiative transfer codes. They often tried to model the "blurring" by using a filter or point-spread-function (PSF). Of course the PSF depends on the height distribution of the scattering particles, mostly aerosols, and must be computed new for each case. Looking at the scattering geometry it became clear that most of the adjacency effect was caused by photons being scattered into the line of sight and then to the observer. By computing the contributions from one surface patch to all volume elements along the line of sight we came up with a very fast and simple method to compute the PSF. First we did it for a uniform scattering phase function and a Lambertian ground reflectance. Soon however we included arbitrary and height dependent phase functions (Henyey-Greenstein) and bi-directional reflectance distribution functions (BRDF). We devised methods to compute the inverse filter of the PSF and used it to sharpen the image. Why do we care about this effect? Much satellite imagery is taken under less than perfect atmospheric conditions and the atmospheric scattering and attenuation must be corrected in order to allow a good classification and interpretation.

In 1992 we went back to the basics of the radiosity method and studied the results of multi spectral calculations using measured leaf spectra. A very simple model was considered, a single layer of leaves above a background. To our surprise we found that the overall reflectance was a nonlinear function of the leaf reflectance/transmittance and the soil reflectance. The overall reflectance could be almost twice what would be expected from single scattering! We plotted the results from our simple model over some experimental data for cotton and got very good agreement. Using probabilities of seeing illuminated and shaded disks in a layered canopy obtained by raytracing we were able to compute spectral BRDF's in a few seconds for canopies with 30 layers. We developed a simple model to compute the overall reflectance of a surface composed of two facets facing each other and illuminated in the plane between the facets. We constructed an experiment and measured the resulting spectra as a function of angle between the facets. The model calculations and measurements are in agreement to within 3 % for small angles. We plan to evolve this model into a terrain effect correction method for satellite imagery and possibly into a new, radiosity based theory for rough surface scattering.

This year we worked on putting together the geometry data for several walnut trees that were measured in the field and reconstructed in great detail with over 40,000 primitives each. We are planning to generate a radiosity solution for an individual tree and generate raytraced images of an orchard of trees. This research will try to invert the canopy chemical composition using hyperspectral imagers which image the Earth over 100 channels. Other researchers, Goel et al (1991), have used a combination of L-systems and radiosity to model scattering of light from plants. Radiosity will be very useful in developing advanced models for complex scenes which are composed of materials of different spectral characteristics. The future sensors on the Earth Observing System (EOS) will possibly use these algorithms. Much of the research in this area has yet to be done.

In conclusion we believe that the radiosity method is able to model important problems in remote sensing by applying computer graphics based algorithms to solve complex radiative transfer problems. We believe there are many more problems that are suitable to be solved by the radiosity method but they are often at the limit of what current computers can tackle. One such problem is to model the bidirectional reflectance of a heterogeneous landscape with 3-d terrain and a non-uniform atmosphere with clouds above in over a hundred wavelengths. The solution would need many surface elements and a large number of volume elements as well (e.g. 512^3).

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